Enhancing Amino Acid Availability and Protein Accretion in Growing Ruminants

DONALD H. BEERMANN*, TODD F. ROBINSON, ORLENA H. CHANG and KATHLEEN D. FINNERTY

Competition between fresh meat species and competition between major producing countries for market share are two reasons for seeking ways to further improve efficiency of meat production in ruminant species. Three other important reasons for developing more efficient management strategies for growing ruminants include the following: 1) reduce the amount of nitrogen and other animal waste products returned to the environment, 2) reduce use of natural resources per unit of meat produced and 3) improve the sustainability of animal agriculture.

The efficiency with which farm animals use energy consumed for protein production varies among species, gender and genotype, and decreases with increasing age and(or) body weight. Efficiency is greatest in the lactating bovine, intermediate in growing nonruminants (chick and pig), and least in growing ruminants (sheep and cattle). Likewise, rate and efficiency of nitrogen use for protein synthesis and deposition in growing ruminants is significantly lower than in growing poultry and pigs. What is the basis for these differences? One possibility is that the quantity and quality (amino acid composition) of absorbed nitrogen in growing ruminants fed conventional diets do not meet the animal's requirements.

Protein and amino acid requirements in growing animals are defined by the sum of whole-body protein and amino acid accretion, synthesis and secretion for endogenous uses (maintenance, necessary enzymes, hormones etc.), and amino acid oxidation. The factors that determine availability and efficiency of amino acid use for protein synthesis and deposition in growing ruminant include level of diet intake, digestibility of the diet, balance of energy substrate and amino acid absorption, and stage of animal growth. Diets can easily be formulated to match amino acid and energy supplies with requirements in nonruminants. However, this is a difficult task in ruminants because the amino acid mixture entering the small intestine usually bears little resemblance, either qualitatively or quantitatively, to dietary amino acid composition as a result of transformations that occur in the rumen. Furthermore, microbial protein production in the rumen may be inadequate under some circumstances (i.e. when microbial protein production is low or requirements are high), and growth performance may be less than optimal unless amino acids of nonmicrobial origin are supplied.

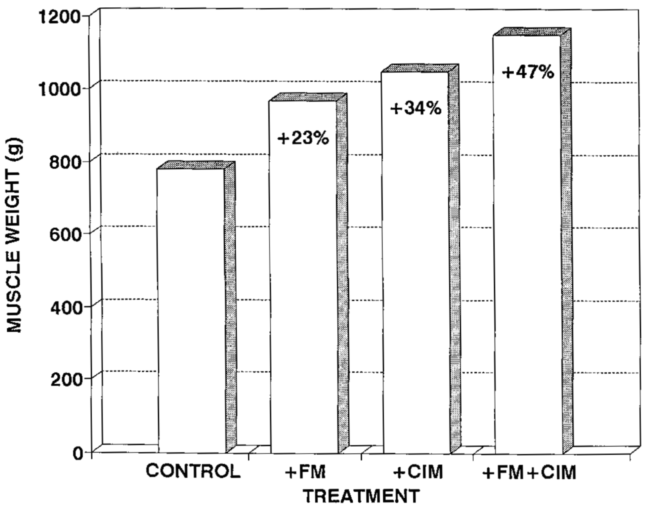
Evidence that conventional mixed forage and concentrate diets may provide an inadequate supply of amino acids to growing ruminants is provided by the data presented in Figure 1. Addition of 3% fishmeal to the diet to replace an equal amount of soy protein increased the weight of individual proximal hind leg muscles by 19% to 28% in ram lambs fed for 70 days from 28 to 48 kg live weight (Beermann et al., 1986). Muscles from lambs fed cimaterol were 20% to 35% larger than muscles from control lambs. When the muscle weights of lambs fed fishmeal and cimaterol were compared to those of lambs fed no fishmeal or cimaterol, these same muscles were 40% to 55% larger. The results demonstrate the additive effects of fishmeal and cimaterol, and suggest that the diet, which contained 16% crude protein, was unable to supply amino acids in sufficient amount or optimal proportions to meet the requirements defined by the genetic capacity for skeletal muscle growth in these lambs.

Similar additivity of response was observed for feed efficiency and weight of the semitendinosus muscles when effects of exogenous somatotropin administration and addition of 4% fishmeal to the diet were studied in wether and ewe lambs (Beermann et al., 1990). These results suggest that the lesser degradability of fishmeal in the rumen allowed more protein to enter and be digested in the abomasum and small intestine, resulting in greater mass of absorbed amino acids and(or) improvement in the balance of individual amino acids absorbed. The enhanced availability of amino acids facilitated greater rates of skeletal muscle growth. Although this concept is not new, studies that demonstrate direct ef-

*D.H. Beermann, T.F. Robinson, O.H. Chang, K.D. Finnerty, Dept. of Animal Science, 53 Morrison Hall, Cornell University, Ithaca, NY 14853-4801.

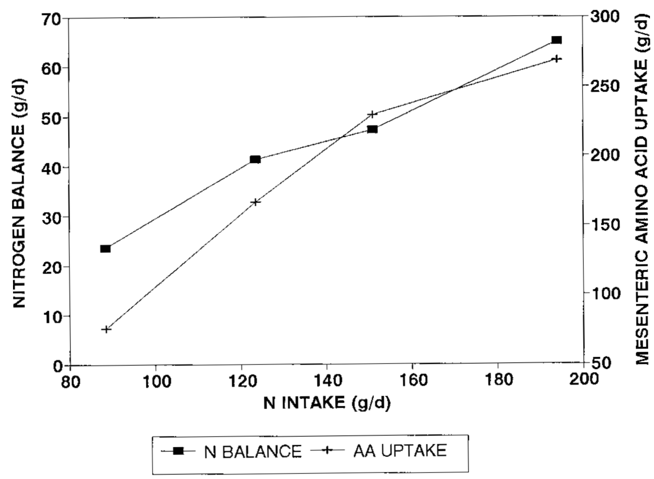
Reciprocal Meat Conference Proceedings, Volume 49, 1996.

FIGURE 1.



Lambs were fed complete isonitrogenous diets containing 0 or 3% fish meal and 0 or 10 ppm cimaterol in a 2x2 factorial arrangement, and offered ad libitum for 10 weeks from 28 to 48 kg live weight. Treatment means are combined weights of the semitendinosus, semimembranosus and biceps femoris muscles (n=4). Percentages are relative increases in combined muscle weights compared with control lambs. Addition of fishmeal and feeding cimaterol increased muscle weights (P<.05) without significant interaction.

FIGURE 2.



Holstein steers (200kg BW) were infused with 4 levels of casein, 0 to 90 g casein nitrogen. Nitrogen balance and total amino acid uptake were significant at P<.05.

fects of feeding protein sources that are resistent to degradation in the rumen on skeletal muscle growth are few. Alternatively, fishmeal may have altered protein metabolism in the rumen through some other influence, as yet unknown. Results from subsequent studies provide evidence for the former.

Results of experiments in which dietary amino acid supply was supplemented by abomasal infusion of casein provide additional evidence that tissue requirements for protein synthesis and deposition are not met in growing ruminants fed conventional diets (see Table 1).

Nitrogen balance was increased 30 and 45% in Dorset wether lambs and Holstein steers, respectively, with abomasal infusion of casein, even though animals were fed at or above NRC requirements for protein. Somatotropin administration also increased N balance approximately 35%, but more notable was the fact that the effects of casein infusion and bST were additive. Whole-body N balance was increased 75% in steers and 89% in lambs when casein infusion and bST were administered together as compared with abomasal infusion of water alone. Interestingly, bST increased the efficiency of use of absorbed N approximately 30% in both studies, but casein infusion did not. Furthermore, the data suggest that the total capacity for use of absorbed amino acids for growth in ruminants may be greater than presumed at present.

Estimates of Total Nitrogen Requirements

We conducted two experiments designed to estimate whole-body tissue amino acid requirements in growing lambs and steers, and to determine the quantity and amino acid composition of absorbed N. Titration of total N requirements was conducted using N balance measurements in response to increasing rates of abomasal protein infusion. Net appearance of alpha-amino N and amino acids in the mesenteric vein were estimated by venous-arterial concentration difference and mesenteric artery blood flow (Transonic model 6R flow probe), using the Fick principle. Data from the lamb experiment (Beermann et al., 1993) are presented in Table 2. Linear increases in alpha-amino N and amino acid appearance in the mesenteric vein (absorption), N retention and average daily gain were observed with increments of whey protein concentrate infusion into the abomasum. The highest N retention observed, 10 g/d, exceeded by 25% the levels observed in lambs of similar genotype fed total mixed diets formulated to maximize N retention (8 g/d). Average daily gains (340 g/d) equalled those achieved under more typical uninstrumented rearing conditions.

Similar relationships were observed in Holstein steers in which casein and glucose were infused into the abomasum (Figure 2, (Robinson et al., 1995)). Whole-body N balance increased from 28 to 62 g/d, at a total N intake of 194 g/d, which is approximately 175% of NRC requirements (NRC, 1985). Although results from these studies indicate that amino acid requirements and maximum N retention capacity of growing lambs and cattle may be considerably greater than previously demonstrated, this does not imply that maximum efficiency of N use is also achieved at maximum rates of N retention. It remains to be determined if these capacities can be achieved by formulating diets to improve amino acid absorption, and whether the relatively

TABLE 1. Effects of Abomasal Casein Infusion and Administration of Bovine Somatotropin on Whole-Body Nitrogen (N) Metabolism[1,2].

	Treatment				
Observation	Water, -bST	Water, +bST	Casein, -bST	Casein, +bST	SEM
LAMBS					
N intake, g/d	16.7[a]	16.7[a]	20.5[a,b]	21.1[b]	0.36
Fecal N, g/d	3.3	3.3	3.0	3.4	0.17
Urinary N, g/d	9.6[a]	8.1[a]	11.8[b]	10.5[a,b]	0.54
N balance, g/d	3.8[a]	5.2[b]	5.6[b]	7.2[c]	0.34
N retained/ N absorbed					
STEERS					
N intake, g/d	123.1[a]	120.8[a]	144.4[b]	140.7[b]	4.8
Fecal N, g/d	42.1	40.5	38.7	38.0	2.4
Urinary N, g/d	51.9[a]	41.6[b]	70.5[c]	51.8[a]	3.1
N blanace, g/d	29.1[a]	38.6[b]	35.2[b]	50.9[c]	1.5
N retained/ N absorbed	0.36[a]	0.48[b]	0.33[a]	0.50[b]	0.07

[1]Dorset wether lambs (23 kg) were fed a mixed diet at 85% of ad libitum intake and infused daily with water or casein and injected s.c. twice daily with 100 ug bST/kg BW or excipient. Means (n=7) within a row with different superscripts differ (P<.05). From Beermann et al., 1991.

[2]Holstein steers (230 kg) were fed twice daily a mixed diet to gain ~ 0.75 kg/d, infused with water or casein and injected daily with 200 ug bST/kg BW per day or excipient. Means (n=4) within a row with different superscripts differ (P<.05). From Houseknecht et al., 1992.

TABLE 2. Effects of Abomasal Protein Infusion on Nitrogen and Amino Acid Absorption and Nitrogen Use in Lambs[1].

	Treatment				
Observation	1	2	3	4	Pooled SEM
Daily feed intake, g/d	595	532	656	649	50
WPC N infused, g/d	0a	3.8[b]	7.6[c]	11.6[d]	0.23
N intake, g/d	12.1[a]	14.7[a]	20.9[b]	24.8[c]	1.08
Urinary N, g/d	5.2[a]	6.4[a]	8.8[b]	11.3[c]	0.85
Fecal N, g/d	3.2	2.9	4.1	3.4	0.32
N balance, g/d	3.7[a]	5.5[a,b]	8.0[b,c]	10.0[c]	0.93
Blood flow, ml/min	329	295	282	317	34.3
a-Amino N absorbed, g/d	2.0[a]	3.0[a]	5.3[a,b]	8.0[b]	1.3
Total AA N absorbed, g/d	2.0[a]	1.5[a]	4.5[a,b]	6.7[b]	1.2

[1]Ram lambs were fed a high concentrate diet at 85% ad libitum in 12 equal portions per day. Whey protein concentrate (WPC) was infused into the abomasum 23 h/d in 4 liters of water, and glucose infusion was altered to maintain isocaloric intakes. Means with different superscripts are different (P<0.05). AA = amino acid. From Beermann et al., 1993.

high efficiencies of N use observed with abomasal infusion of protein can be attained with these diets. A series of experiments were undertaken to address these issues.

Quality Versus Quantity of Absorbed Amino Acids

To determine if efficiency of protein (amino acid) use for growth could be altered by changing the source of proteins in the diet, a N balance trial was conducted to compare effects of 0, 2, 4, 6, 8 and 10% fishmeal in isonitrogenous diets on N metabolism (Cheng et al., 1995). Results are presented in Table 3. N balance increased from 8.2 g/d to 9.4 g/d and urinary N was reduced from 8.2 g/d to 6.8 g/d as the amount of fishmeal in the diet increased from 0 to 8%, without significant change in fecal N. The biological value, defined as g N retained divided by g N absorbed, increased from 0.5 to .58 as the amount of fishmeal added was increased from 0 up to 8% (P<.025). Results demonstrate that efficiency of N use is increased when fishmeal is added to the diet to replace an equal amount of N from soy and corn. This improvement in efficiency suggests that amino acid composition of the absorbed N was improved to better match the pattern of amino acids used by lean tissues for protein synthesis and deposition.

Availability of amino acids to the small intestine of the ruminant can be altered by feeding protein sources that are resistent to rumen degradation (see review by Merchen and Titgemeyer (1992)). Titgemeyer et al., (1989) found that 21, 68, 86 and 92% of the protein in soybean meal, fishmeal, corn gluten meal and blood meal, respectively, escapes rumen degradation. The amino acid composition of the total N reaching the small intestine is different for each protein source. O'Connor et al. (1993) summarized the amino acid content of the insoluble protein in several common feeds. Corn gluten meal is a poor source of lysine, but a good source of leucine and the sulfur amino acids, while blood meal is a poor source of methionine, isoleucine and tyrosine and excellent for leucine, lysine, valine, phenylalanine and histidine. Fishmeal is also high in lysine, but it is a poor source of cysteine (Merchen and Titgemeyer, 1992). The conclusions of Blake and Stern (1988), Titgemeyer et al. (1989), Cecava et al. (1990) and Goedeken et al. (1990) agree, based on amino acid disappearance from the small intestine, that combining escape protein sources will provide an optimal amino acid composition to enhance growth in ruminants fed corn or corn-soy based diets.

To investigate further whether amino acid composition of the protein source might be a critical factor, effects of abomasal infusion of fishmeal, bloodmeal, casein and isolated soy protein on N balance were compared in lambs. Results are presented in Table 4. Abomasal infusion of 6 gN/d in four equal portions (1.5 g) increased N balance 2.5 g/d over the 4.8 g/d observed with the water infusion control, and no differences were observed between all four protein sources. These results suggest that mass of absorbed N is potentially more important than amino acid composition when corn

TABLE 3. Nitrogen Metabolism Responses to Incremental Fishmeal Replacement of Soy and Corn Protein in Diets Fed to Ram Lambs[1].

	Percentage of fishmeal in the diet						
Observation	0	2	4	6	8	10	P<
DM intake, g/d	878	877	819	876	902	842	NS
N intake, g/d	22.2	22.5	19.7	21.5	22.2	19.8	0.05
Urinary N, g/d	8.2	8.1	7.3	7.2	6.8	7.2	0.10
Fecal N, g/d	5.9	6.0	5.4	5.7	6.0	5.4	NS
N blanace, g/d	8.2	8.4	7.0	8.6	9.4	7.3	0.001
Biological value	0.50	0.50	0.49	0.55	0.58	0.50	0.025
ADG, g/d	289	286	257	295	265	265	NS

[1]Lambs (n=6, 21 kg BW) were fed a complete mixed diet at 95% ad libitum in two equal portions per day. NS = Not significant.
From Cheng et al., 1995.

TABLE 4. Effects of Abomasal Infusion of Protein Sources With Different Amino Acid Compositions on Nitrogen Use in Lambs[1].

	Treatment					
Observation	Water	CAS	BM	FM	ISP	P<
Feed N, g/d	14.9	14.9	14.4	15.0	14.8	NS
N infused, g/d	0	6.00	6.15	5.95	6.00	—
Fecal N, g/d	5.5	4.98	5.00	5.59	4.92	NS
Urinary N, g/d	4.67	8.24	8.11	8.08	9.03	0.002
N balance	4.75	7.27	7.4	7.29	6.89	0.004
N response, g/d	—	2.52	2.64	2.53	2.14	NS
Plasma urea N, mg/dL	6.3	10.7	10.8	10.4	10.2	0.024
Average gain, g/d	153	252	272	184	187	0.115

[1]Ram lambs (n=5, 26 kg BW) were fed a high concentrate diet at 90% ad libitum in 4 equal amounts per day. CAS = casein; BM = blood meal; FM = fishmeal; ISP = Isolated soy protein; NS = Not significant.

TABLE 5. Diet Composition for the UIP Nitrogen Balance Experiment (DM Basis, g/kg).

	Treatment				
Ingredient	A	B	C	D	E
Grass hay	9.4	9.4	9.4	9.4	9.4
Ground corn	81.7	79.5	77.3	75.1	72.9
Soybean meal	6.4	4.8	3.2	1.6	0
Beef tallow	0	.5	1.0	1.6	2.1
Blood meal	0	.6	1.1	1.7	2.2
Hydrolyzed feather meal	0	.6	1.1	1.7	2.2
Fishmeal	0	.7	1.4	2.2	2.9
Meat and bone meal	0	1.1	2.2	3.2	4.3
Dicalcium phosphate	1.0	1.0	1.0	1.0	1.0
Salt and trace minerals	1.0	1.0	1.0	1.0	1.0
Crude protein, %	11.4	12.8	13.6	15.4	16.2
Rumensin	Added at 30 g rumensin/909 kg feed				

and ground hay diets containing soy protein supplements are fed. Alternatively, however, the differences in amino acid composition of each protein source may have been too small to significantly improve the composition of amino acids absorbed relative to total requirements. A better approach would be to administer a combination of protein sources that complement each other in improving amino acid composition of absorbed nitrogen. This was undertaken in two additional studies in which a model was used to formulate an undegraded intake protein mixture to be added as a supplement to corn-based diets for growing/finishing cattle.

The Cornell Net Carbohydrate and Protein System (CNCPS) model has been developed to predict the kinetics of feed carbohydrate and protein fractions, rumen fermentation, quantity of amino acids absorbed and tissue amino acid requirements of cattle (Fox et al., 1992; Russell et al., 1992; Sniffen et al., 1992, O'Connor et al., 1993; Ainslie et al., 1993). The amino acid balance component of the model has not been fully validated, but offered a tool for us to test the hypothesis that improved amino acid balance in growing ruminants will improve growth rates and efficiency of gain. This model was used to formulate diets by balancing protein intake and amino acid composition of absorbed nitrogen, based on protein source resistance to degradation in the rumen and amino acid composition of individual protein sources, while also assuring that nutrient requirements of rumen microbes are met.

An experiment was designed using six Holstein steers weighing approximately 600 kg to determine whether rate and efficiency of consumed protein use for growth could be improved by feeding a mixture of meat and bone meal, blood meal, fishmeal and hydrolyzed feather meal that was formulated to optimize amino acid absorption. Compositions of the basal diet and the four treated diets are presented in Table 5. The ratio of the four protein sources was held constant, and amounts fed increased from 0 to 2.5, 5.0, 7.5 and 10% of the dry matter intake. This design allows estimation of the optimal amount of undegraded intake protein (UIP), of known amino acid composition, that should be added to conventional corn-based feedlot diets. Beef tallow was added to make the diets isocaloric. Animals were fed hourly equal amount of the diets at 95% of ad libitum intake for periods of 18 days each. Diets were fed in random order and N balance collections were conducted after 7 days of adjustment to each diet. The steers received daily sc injections of estradiol 17-ß to mimic the effects of an estrogenic implant. The steers were also surgically instrumented to accommodate other metabolic measurements.

Results are presented in Table 6. Average daily gain increased with each level of addition of the UIP mix up to 7.8% (treatment D). Daily N intake increased from 80 to 118 g/d with addition of the UIP mix, and although fecal and urinary N excretion were increased numerically, these changes were not statistically significant. Daily N retention increased with each level of addition of the UIP mixture, from 18.8 g/d to 42.7 g/d, an increase of 127%. Biological

TABLE 6. Effects of Feeding Increasing Amounts of an Amino Acid-Balanced By-Product Protein Mixture to Holstein Steers[1].

	Diet Treatments						
	A	B	C	D	E	S_x	Probability
Number of steers	6	6	6	6	6		
Initial weight, kg	267	272	266	271	267	10.2	NS (P<.990)
Final weight, kg	276	284	280	288	284	10.0	NS (P<.919)
Average daily gain, kg	0.55	0.71	0.84	1.04	0.90	0.172	NS (P<.343)
Daily feed intake, kg	4.624	4.896	4.861	5.281	4.843	0.214	NS (P<.330)
Daily N intake, g	80.1	95.3	101.9	117.0	118.0	4.65	P<.001
Daily fecal N, g	28.1	30.8	31.0	36.7	32.9	1.58	P<.014
Daily urinary N, g	33.1	34.0	38.2	42.6	42.4	3.56	NS (P<.217)
Daily N balance, g	18.8	30.6	32.7	37.6	42.7	5.03	P<.04
Biological value[2]	35.3	45.2	45.2	46.5	48.9	6.08	NS (P<.58)
Plasma urea N, mg/dL	4.5	4.9	4.9	4.4	5.4	.91	NS (P<.95)

[1]*Values are means for treatment diets which contained 0, 2.6%, 5.2%, 7.8% and 10.4% of the protein mixture by weight on a DM basis. Steers received twice daily injections of 500 µg estradiol 17-ß. Treatment periods were 17 days, d1-7 for adjustment, d8-14 for N collections, d15-17 for digesta collections.* S_x *= standard error of the mean.*

[2]*Biological value =* $\dfrac{\text{N retained}}{(\text{N intake - Fecal N})}$

value, a measure of efficiency of N use, increased by 40% from 35.3 to 48.9. These data and lack of increase in plasma urea N concentrations show that efficiency of N use was improved, along with significantly increasing the rate of N retention. The results provide strong evidence that careful diet formulation to provide proper balance and mass of absorbed amino acids to meet requirements for growth is possible. With this improved nutritional management strategy comes improved rates of protein deposition, increased efficiency of energy and protein use for growth and hopefully, improved composition of gain. A comparative slaughter experiment designed to evalute the effects of feeding crossbred beef steers 0, 3, 6 or 9% of the diet as an amino acid-balanced UIP mixture is currently in progress.

Summary

In conclusion, results from the several studies presented indicate that rate of skeletal muscle growth and protein accretion in growing sheep and cattle may be limited by amino acid quantity and(or) quality of absorbed N, despite the fact that diets fed were formulated to optimize rumen fermentation and provide protein in excess of current NRC requirements. Feeding protein sources that are resistant to degradation in the rumen and use of metabolism modifiers are two strategies for enhancing amino acid availability for skeletal muscle growth in ruminants. Using them in combination may be necessary to fully optimize efficiency and rate of N use for growth, while also minimizing return of N to the environment. The extent to which this may be achieved, and the mechanisms involved are yet to be fully understood.

Competitiveness and sustainability of meat production using ruminants can be enhanced through more precise nutritional management to better match mass and balance of amino acids absorbed to tissue requirements. The CNCPS model is an effective tool to achieve this goal.

References

Ainslie, S.J.; Fox, D.G.; Perry, T.C.; Ketchen, D.J.; Barry, M.C. 1993. Predicting amino acid adequacy of diets fed to Holstein steers. J. Anim. Sci. 71:(1312-1319).

Beermann, D.H.; Hogue, D.E.; Fishell, V.K.; Dalrymple, R.H.; Ricks, C.A. 1986. Effects of cimaterol and fishmeal on performance, carcass characteristics and skeletal muscle growth in lambs. J. Anim. Sci. 62:370-379.

Beermann, D.H.; Hogue, D.E.; Fishell, V.K.; Aronica, S.; Dickson, H.W.; Schricker, B.R. 1990. Exogenous human growth hormone releasing factor and ovine somatotropin improve growth performance and composition of gain in lambs. J. Anim. Sci. 68:4122-4133.

Beermann, D.H.; Robinson, T.F.; Byrem, T.M.; Hogue, D.E.; Bell, A.W.; McLaughlin, C.L. 1991. Abomasal casein infusion and exogenous somatotropin enhance nitrogen utilization by growing lambs. J. Nutr. 121:2020-2028.

Beermann, D.H.; Robinson, T.F.; Byrem, T.M.; Bell, A.W.; Hogue, D.E. 1993. Effects of abomasal protein in fusion on nitrogen and amino acid absorption and nitrogen utilization in growing lambs. The FASEB J. 7(4):A604. Abstr.#3500.

Blake, W.L.; Stern, M.D. 1988. Influence of protein source on amino acid profile of effluent flowing from continuous culture of ruminal contents. J. Anim. Sci. 66:2284-2298.

Cecava, M.J.; Merchen, N.R.; Berger, L.L.; Fahey, Jr., G.C. 1990. Intestinal supply of amino acids in sheep fed alkaline hydrogen peroxide-treated wheat straw-based diets supplemented with soybean meal or combinations of corn gluten meal and blood meal. J. Anim. Sci. 68:467-477.

Cheng, O.H.; Beermann, D.H.; Robinson, T.F.; Finnerty, K.D.; Weingardt, K.; Moloney, A.P.; Hogue, D.E. 1995. Nitrogen metabolism responses to incremental fish meal replacement of soybean meal in diets fed ram lambs. J. Anim. Sci. 73(Suppl. 1):138.

Fox, D.G.; Sniffen, C.J.; O'Connor, J.D.; Russell; J.B.; Van Soest, P.J. 1992. A net carbohydrate and protein system for evaluating cattle diets: III. Cattle requirements and diet adequacy. J. Anim. Sci. 70:3578-3596.

Goedeken, F.K.; Klopfenstein, T.J.; Stock, R.A.; Britton, R.A.; Sindt, M.H. 1990. Protein value of feather meal for ruminants as affected by blood addition. J. Anim. Sci. 68:2936-2944.

Houseknecht, K.L.; Bauman, D.E.; Fox, D.G.; Smith, D.F. 1992. Abomasal infusion of casein enhances nitrogen retention in somatotropin-treated steers. J. Nutr.122:1717-1725.

Merchen, N.R.; Titgemeyer, E.C. 1992. Manipulation of amino acid supply to the growing ruminant. J. Anim. Sci. 70:3238-3247.

NRC. National Research Council. 1985. Ruminant nitrogen usage. National Academy Press, Washington D.C.

O'Connor, J.D.; Sniffen, C.J.; Fox, D.G.; Chalupa, W. 1993. A net carbohydrate and protein system for evaluating cattle diets: IV. Predicting amino acid adequacy. J. Anim. Sci. 71:1298-1311.

Robinson, T.F.; Beermann, D.H.; Byrem, T.M.; Ross, D.E.; Fox, D.G. 1995. Effects of abomasal casein infusion on mesenteric drained viscera amino acid absorption, hindlimb amino acid net flux and whole body nitrogen balance in Holstein steers. J. Anim. Sci. 73(Suppl. 1):140.

Russell, J.B.; O'Connor, J.D.; Fox, D.G.; Van Soest, P.J.; Sniffen, C.J. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal fermentation. J. Anim. Sci. 70:3551-3561.

Sniffen, C.J.; O'Connor, J.D.; Van Soest, P.J.; Fox, D.G.; Russell, JB. 1992. A new carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. J. Anim. Sci. 70:3562-3577.

Titgemeyer, E.C.; Merchen, N.R.; Berger, L.L. 1989. Evaluation of soybean meal, corn gluten meal, blood meal and fish meal as sources of nitrogen and amino acids disappearing from the small intestine of steers. J. Anim. Sci. 67:262-275.

Titgemeyer, E.C.; Merchen, N.R. 1990. The effect of abomasal methionine supplementation on nitrogen retention of growing steers postruminally infused with casein or nonsulfur-containing amino acids. J. Anim. Sci. 68:750-757.